[redacted] Declassified 1-10-46

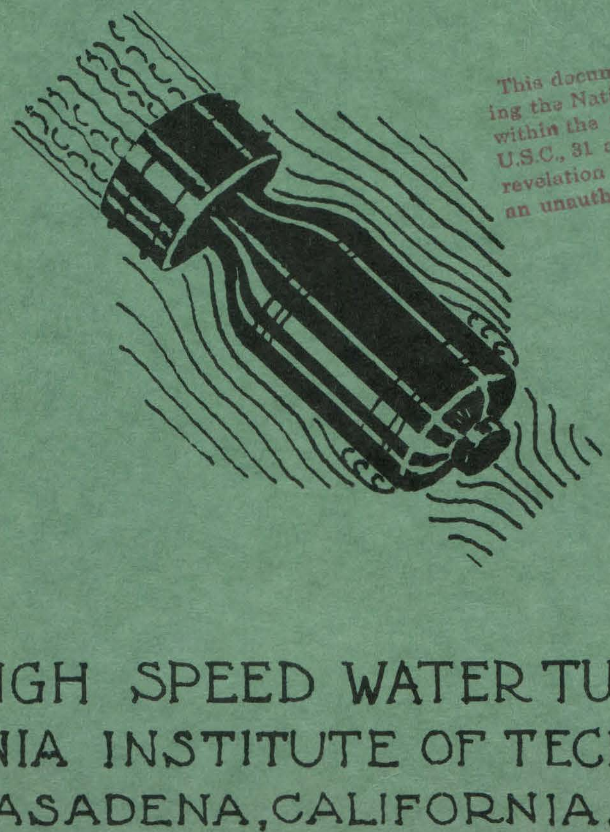
OFFICE OF SCIENTIFIC RESEARCH & DEVELOPMENT

NATIONAL DEFENSE RESEARCH COMMITTEE.

DIVISION SIX-SECTION 6.1

ND-23 Knapp.

WATER TUNNEL TESTS
OF THE
15 CM. GERMAN SPINNER ROCKET.



THE HIGH SPEED WATER TUNNEL

CALIFORNIA INSTITUTE OF TECHNOLOGY

PASADENA, CALIFORNIA.

SECTION Nº 6.1-sr-207-932

HML REP. Nº ND 23.

[redacted]

CONFIDENTIAL

(CONFIDENTIAL)

Office of Scientific Research and Development
National Defense Research Committee
Division Six - Section 6.1

WATER TUNNEL TESTS
OF THE
15 CM. GERMAN SPINNER ROCKET

by

Robert T. Knapp
Official Investigator

The High Speed Water Tunnel
at the
California Institute of Technology
Hydraulic Machinery Laboratory
Pasadena, California

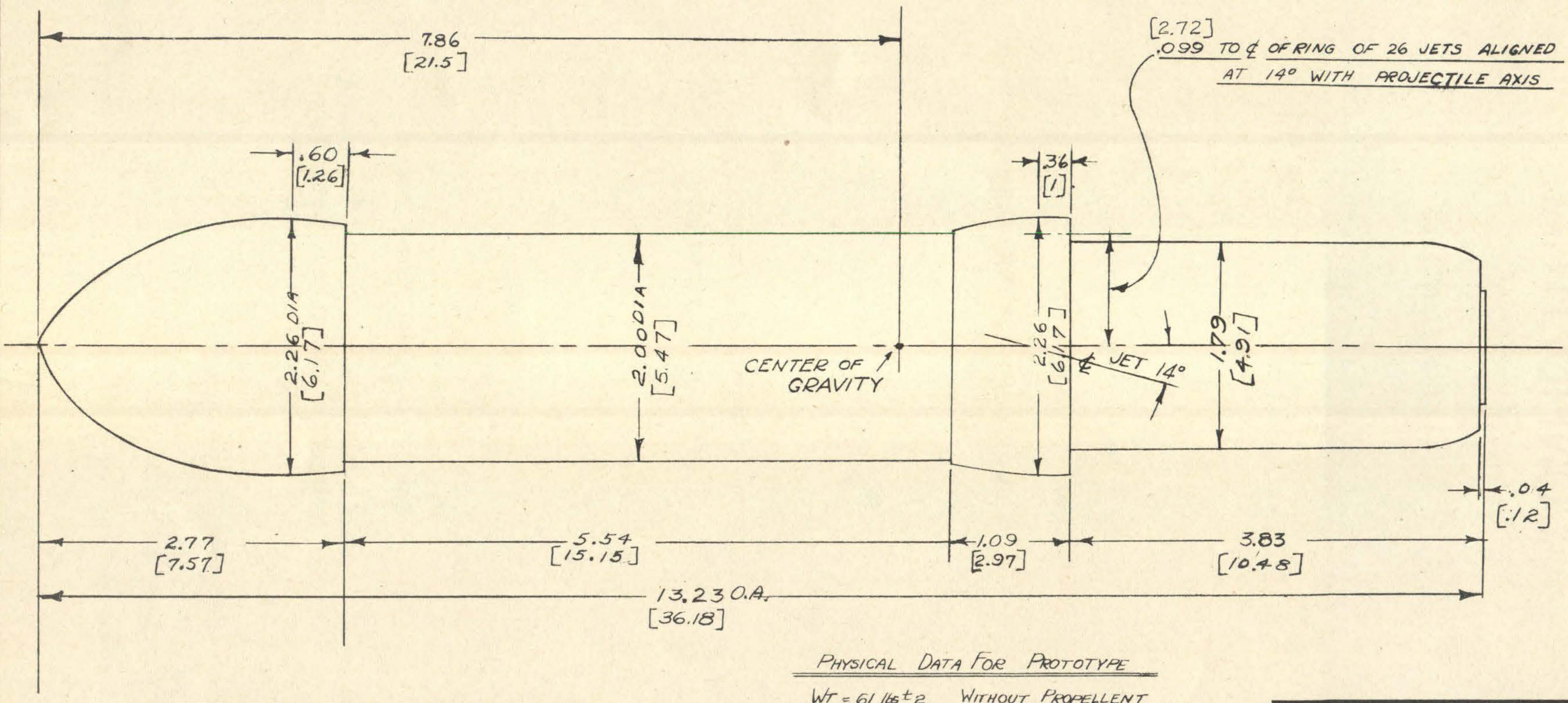
Section No. 6.1-sr-207-932

HML Rep. No. ND-23

November 11, 1943

CONFIDENTIAL

FIG. 1



NOTE - PROTOTYPE DIMENSIONS ARE SHOWN IN BRACKETS

PHYSICAL DATA FOR PROTOTYPE

WT = 61 lbs ± 2 WITHOUT PROPELLENT
= 75.3 lbs ± 2 WITH PROPELLENT
A = AXIAL MOMENT OF INERTIA
= 0.0625 SLUGS - Ft^2
B = TRANSVERSE MOMENT OF INERTIA
= 1.06 SLUGS - FT^2

CONFIDENTIAL

HYDRAULIC MACHINERY LABORATORY CALIFORNIA INSTITUTE OF TECHNOLOGY PASADENA, CALIFORNIA	
DIMENSIONS FOR 15 CM. GERMAN SPINNER ROCKET	
DR HCY 9/20/43	SCALE
CH CRA 10/2/43	ND-529 -U
AP	

MEMORANDUM ON WATER TUNNEL TESTS OF THE

15 CM. GERMAN SPINNER ROCKET

This memorandum covers Water Tunnel Tests of the 15 cm. German Spinner Rocket. The tests were made at the request of the Ballistic Research Laboratory of the Aberdeen Proving Ground. A photograph of the 2" diameter model used for the tests is shown in Figure 2. Overall dimensions of the model and dimensions and physical data for the full-scale projectile are shown in Figure 1.

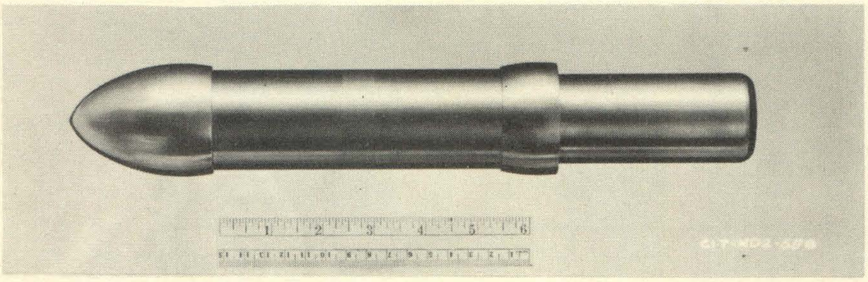


Figure 2

2" Diameter Model of the

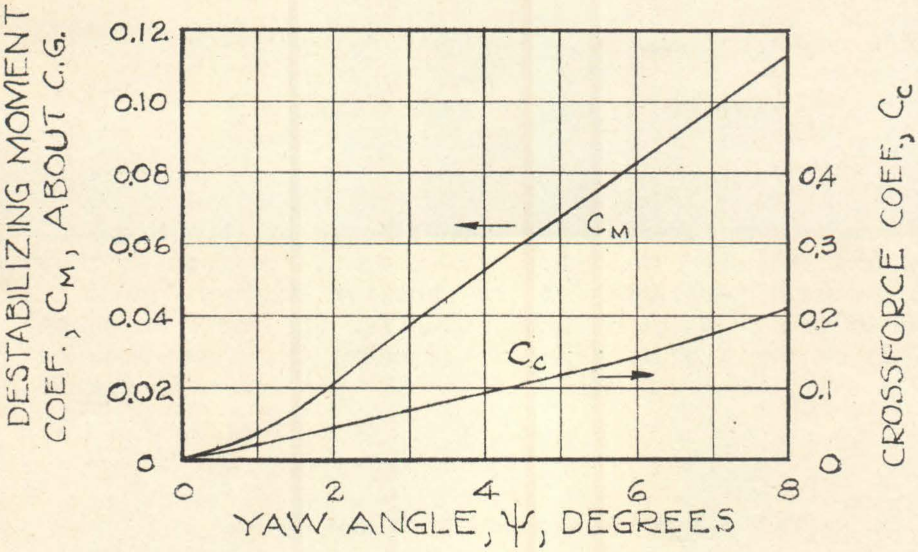
15 cm. German Spinner Rocket

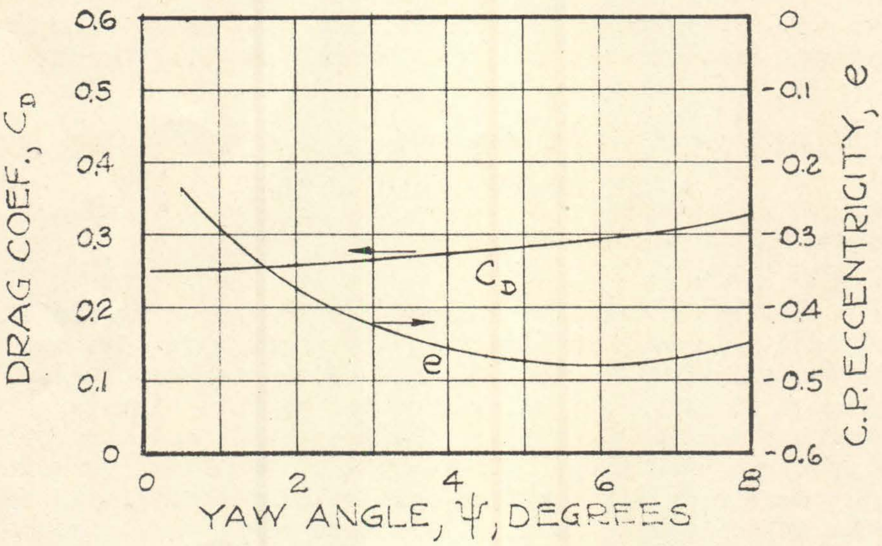
This rocket has a velocity somewhat above the sonic and is spin stabilized. As seen in Figure 1, the propulsive jets are located in the enlarged section just aft of the center of gravity and are aligned at 14° with the axis of the rocket. The tangential component of the jet reaction spins the projectile and thus provides the required stability. The results of the Water Tunnel tests, which were made without spin, are valid for flight in water or in air at velocities below about 750 feet per second. For flight in air at velocities near or above sonic, the results are not directly applicable.

Curves showing the variation of the drag, cross force, and moment coefficients with yaw angle, and of center-of-pressure eccentricity with yaw angle are shown in Figure 3. Definitions of terms and coefficients used in this figure are given at the end of this memorandum. The data in Figure 3 have been corrected for support interference effects.

These curves show that the rocket as tested is unstable. The destabilizing moment coefficient, C_M, and the negative center-of-pressure eccentricity, e, both show that the center of pressure lies ahead of the center of gravity. Furthermore, the increasing values of e from -0.24 at 1/2° yaw to -0.45 at 8° yaw show that

 CONFIDENTIAL





$$C_D = \frac{D}{\rho \frac{V^2}{2} A_D} \qquad A_D = 0.208 \text{ FT.}^2$$

$$C_c = \frac{C}{\rho \frac{V^2}{2} A_D} \qquad L = 3.01 \text{ FT.}$$

$$C_M = \frac{M}{\rho \frac{V^2}{2} A_D L} \qquad L_{cg} = 1.73 \text{ FT.}$$

$$e = \frac{L_{cp} - L_{cg}}{L}$$

15 cm. GERMAN SPINNER ROCKET

RUNS 1 & 2 OCT. 16, 1943

HIGH SPEED WATER TUNNEL
AT THE
CALIFORNIA INSTITUTE
OF TECHNOLOGY

CONFIDENTIAL

SHEET ND 23-1580-L

FIG. 3.

the rocket becomes more unstable as the yaw angle increases from zero. These results are normal since the rocket is stabilized by spinning, and, hence, has no tail fins or rings as stabilizers. The drag coefficient is 0.25 at zero yaw and increases to 0.33 at 8° yaw. The cross force coefficient increases approximately linearly with yaw at a rate of 0.025 per degree.

It is interesting to note that the above characteristics are roughly similar to those that have been measured for simple cylindrical projectiles with either ogive or hemispherical noses and square trailing ends. For example, a cylinder with hemispherical nose six calibers long (note that rocket is 5.85 calibers long) has a drag coefficient of 0.275 at zero yaw, and increases to 0.40 at 8°. The eccentricity varies from -0.33 at zero yaw to -0.39 at 8°. The reason for this similarity lies in the fact that both the present Spinner Rocket and the simpler "bullets" have the same general cylindrical shape with rounded nose and blunt, trailing end. Of course, as the velocity of sound is approached or exceeded, these statements no longer apply since nose shape then becomes of paramount importance. It can be said, as a first approximation, that for simple bullet shaped bodies traveling at subsonic speeds, the afterbody and tail shapes largely determine the aerodynamic forces, whereas for supersonic speeds, the nose shape is the predominating influence.

An interesting indirect measure of the deviation of the subsonic characteristics from those at supersonic velocities can be obtained by making use of the spinning stability criterion and the propulsive nozzle alignment angle.

According to Hayes,* the condition for stable motion of a spinning projectile is

$$\frac{A^2 N^2}{4 B \mu} > 1 \qquad (1)$$

or

$$\frac{A^2 N^2}{4 B \frac{C_M}{\psi} \rho \frac{V^2}{2} A_D L} > 1$$

where

A = axial moment of inertia in slugs-ft^2

N = spin in radians per sec

B = transverse moment of inertia in slugs-ft^2

* "Elements of Ordnance" by Col. Thomas J. Hayes, Wiley, 1938 Page 417

μ = moment factor in foot-lbs per radian of yaw

$$= \frac{M}{\psi} = \frac{C_M}{\psi} \rho \frac{V^2}{2} A_D L$$

For projectiles spun by rocket jets the stability requirement can be written in terms of the angle which the jet center line makes with the projectile axis. This is accomplished as follows: The relations between impulse of the jets and the resulting linear and angular momentums can be written

$$(F \cos \Theta)t = mV$$

$$Tt = (F \sin \Theta)rt = AN$$

or eliminating t between the two expressions

$$N = \frac{mVr \tan \Theta}{A} \qquad (2)$$

where

V = maximum velocity reached by rocket in feet per second

F = jet reaction in lbs

t = burning time of propellant in seconds

m = mass of projectile in slugs

T = torque exerted by jets about projectile axis in lb-ft

r = radius to center line of jet ring in ft

Θ = jet alignment angle

If the value for the spin velocity, N, given by this equation is substituted in the stability relation (1) above and the resulting relation rearranged, the following expression for the required jet angle is obtained:

$$\tan \Theta > \frac{1}{mr} \left\{ 2B\rho A_D L \frac{C_M}{\psi} \right\}^{1/2} \qquad (3)$$

In this equation Θ and $C_{M/\psi}$ are the variables, all other quantities being constant for a given projectile. If values of $C_{M/\psi}$ from the Water Tunnel tests are used to evaluate Θ, an angle of approximately 6° is obtained as the minimum jet angle for stability at subsonic velocities. Since, as equation (2) shows, N varies directly with tan Θ, the actual jet angle of 14° shows that the stability coefficient, $\frac{A^2N^2}{4B\mu}$, has a value of about 5.63 instead of the minimum of 1. Although a part of this large excess is undoubtedly needed to provide the desired "stiffness" to the rocket, it is probable that this high value indicates that, at supersonic velocities, the destabilizing aerodynamic moment coefficient is considerably greater than it is at subsonic speeds.

Definitions of terms, symbols, and coefficients used on curve sheets

D = drag force in lbs

C = cross force in lbs

M = moment in foot-lbs about a transverse axis through the center of gravity

C.P. = center of pressure. The point in the axis of the projectile at which the resultant of all forces acting on the model is applied.

e = center-of-pressure eccentricity. The distance between the center of pressure (C.P.) and the center of gravity (C.G.) expressed as a fraction of the projectile length

ρ = density of water (or air) in slugs per cu ft

V = relative velocity between water (or air) and projectile in feet per second

A_D = area in square feet of the maximum cross section normal to the projectile axis

L = overall length of the projectile in feet

C_D = drag coefficient

$$= \frac{D}{\rho \frac{V^2}{2} A_D}$$

C_C = cross force coefficient

$$= \frac{C}{\rho \frac{V^2}{2} A_D}$$

C_M = moment coefficient

$$= \frac{M}{\rho \frac{V^2}{2} A_D L}$$